

**SWATCH TEST RESULTS OF COMMERCIAL CHEMICAL  
PROTECTIVE BOOTS TO CHALLENGE  
BY CHEMICAL WARFARE AGENTS:  
SUMMARY REPORT**

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## **EXECUTIVE SUMMARY**

As part of the Domestic Preparedness Program, nine commercially available boot designs were tested to assess their capability to protect in a chemical warfare (CW) agent environment. Swatches of material from each boot design were tested for resistance to permeation for Sarin (GB) and mustard (HD). From this data, the author calculated the estimated time it would take to permeate the boot with sufficient agent to cause physiological effects in a person wearing the boot. The tests are described and the calculated breakthrough times are presented.

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## **PREFACE**

The work described in this report was authorized under the Expert Assistance (Equipment Test) Program for the U.S. Army Soldier and Biological Chemical Command (SBCCOM) Program Director for Domestic Preparedness.

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Dr. Jimmy Perkins, University of Texas School of Public Health, San Antonio, TX.  
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Leo F. Saubier, Battelle Memorial Institute, Edgewood, MD.

The panel reviewed and commented on the test procedures, instrumentation, data analysis and presentation. Their guidance was a valuable element in the development of clear and adequate descriptions of the concepts and procedures used in these tests.

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# TEST RESULTS OF COMMERCIAL CHEMICAL PROTECTIVE BOOTS TO CHALLENGE BY CHEMICAL WARFARE AGENTS: SUMMARY REPORT

## 1. INTRODUCTION

In 1996, Congress passed Public Law 104-201 (Defense Against Weapons of Mass Destruction Act of 1996), directing the Department of Defense (DoD) to assist other federal, state, and local agencies in enhancing preparedness for terrorist attacks using weapons of mass destruction. The DoD responded by forming the Domestic Preparedness Program that same year. One of the objectives of the Domestic Preparedness Program is to enhance federal, state and local emergency and hazardous material (HAZMAT) response to nuclear, biological and chemical (NBC) terrorism incidents. As part of an effective response, emergency and HAZMAT personnel who are responding to an incident will use personal protective equipment (PPE) to protect them from exposure to chemical agents or biological agents. The specific PPE that would be used by these federal, state and local emergency and HAZMAT personnel would depend upon the situation encountered and what PPE is held in inventory. In some cases, chemical protective boots may be required to enter a contaminated or potentially contaminated area.

## 2. OBJECTIVES

This study evaluates some commercially available and commonly used chemical protective boots to assess how well they resist vapor permeation from liquid contamination by chemical agents Sarin (GB) and mustard (HD). This information is intended for federal, state and local emergency and HAZMAT personnel as an aid in their evaluation (and possible modification) of current work rules regarding specific chemical protective boots currently in inventory and as an aid in future procurement of appropriate chemical protective boots. This is especially important if these personnel choose to include military chemical agent protection as a

criterion. The information supplements data and information provided by the boot manufacturers. The boots are tested in new, as-received condition. The effects of aging, temperature extremes, laundering, and other factors are beyond the intended scope of this test program. These tests are conducted to assess percutaneous (i.e. skin) protection only.

### 3. TESTING AND DATA ANALYSIS

#### 3.1 Testing Overview.

The chemical protective boots that are tested in this test program are listed in Appendix A. Testing consisted of a permeation test of material swatches to measure the permeation of both GB and HD through the swatches.

#### 3.2 Liquid Challenge/Vapor Permeation Testing (Agent Swatch Testing)

##### 3.2.1 Liquid Challenge/Vapor Permeation Testing Procedures.

This testing is conducted to measure the vapor permeation of chemical agents GB and HD through boot swatches over a 24-hr period. The test is intended to assess how well the boot materials resist vapor permeation. The amount of agent applied and duration of exposure do not represent any particular threat that responders may encounter, but they do serve as a common point of reference for all test results.

The test methodology was taken from TOP 8-2-501<sup>1</sup> and is described in Appendix B. Twelve swatches were cut from two pairs of each boot design to be tested. Due to limited availability of certain boot designs, the management decision was made to cut swatches from two pairs, rather than the six pairs originally called for, to meet the program schedule. All

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<sup>1</sup> Test Operations Procedure (TOP) 8-2-501, Permeation and Penetration of Air-Permeable, Semipermeable and Impermeable Materials with Chemical Agents or Simulants (Swatch Testing). U.S. Army Dugway Proving Ground, UT. 3 March 1997, UNCLASSIFIED Report (AD A322329).

swatches were taken approximately midway up the side of the boot. Six of the swatches were allocated to GB testing and the remainder were allocated to HD testing. Swatches are taken from silicone (M45 military mask formulation) slabs for use as a source of HD or GB vapor after contamination.

Laboratory personnel apply a predetermined liquid agent challenge of 10 g/m<sup>2</sup> to the top surface of each swatch.

The permeation test apparatus contains seven test cells. For each test, swatches from one boot design were placed in six of the cells (normal swatch sequence is boot 1, boot 2, boot 1, boot 2, boot 1 and boot 2) and a silicone swatch was placed in the seventh cell. In the analysis, each swatch was assumed to represent the area covered by the boot; the foot and the lower leg.

Agent droplets are applied to the surface of the first swatch at time zero. Agent is then applied to the surface of each succeeding swatch at 3-min intervals. The upper chamber of each test cell is sealed. A 1.0 L/min flow of air, from the test cabinet, is maintained in the lower test cell chamber beneath each swatch.

During the 24-hr test period, gas samples are taken on a sequential basis by a laboratory MINICAMS™ with stream selection system (a miniaturized gas chromatograph with flame photometric detector and sampling system (from OI Analytical, CMS Field Products Group, Birmingham, AL)). Gas sampling by the MINICAMS™ begins for the first swatch approximately 3 min following agent application. Subsequent 3-min cycles of the MINICAMS™ are composed of 2 min of desorption of collected agent vapor from the pre-concentrator tube (PCT) onto the column followed by 1 min of gas sampling (collection of agent

vapor in the PCT). Sampling is sequential through six boot material swatches, the silicone swatch,<sup>2</sup> and three blank gas samples (taken from the test cabinet to purge the sampling line before repeating the sampling sequence). The six boot material swatches, the silicone swatch, and three blanks are all sampled for the first time within the first 30 min of the test. Then the sampling sequence begins anew.

The MINICAMS™ first determines the amount of agent vapor in each gas sample. Using this result, the amount (ng) of agent vapor present in the airstream that passes beneath the swatch over the time from the previous gas sample to the current gas sample is determined by the MINICAMS™ permeation software. The calculations assume that the permeation change with time is a straight line over the 30 min interval. The permeation for each time interval is the average of the permeation rates (flux, ng/cm<sup>2</sup>/min) for the current and previous gas samples multiplied by 30 min. This amount of agent vapor is presumed to be the amount that has permeated the swatch over that time interval. The cumulative mass of agent permeating the swatch per unit area at any elapsed time during the 24-hr test is defined as  $M_f$ . It is based on the mass permeated in the time interval over the effective swatch area, which is the opening in the permeation cell (10 cm<sup>2</sup>), and is determined by the MINICAMS™ permeation software. Over the 24-hr test period, a series of  $M_f$  values is calculated for each swatch.

### 3.2.2 Liquid Challenge/Vapor Permeation Testing Analysis.

Each boot design has  $M_f$  data for six swatches for each of the two agents over the

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<sup>2</sup>Originally, it was intended to use silicone swatches as references or controls, but it was soon found that permeation through the silicone varies too widely for it to be used for that purpose. Silicone swatches were used anyway, because they serve as a reliable source of agent vapor to assure the tester that the MINICAMS® is responding properly during tests when little or no agent permeates the actual test swatches.

24-hr test period. For this report, the average (of six swatches) cumulative permeation ( $M_f$ ) is calculated for each agent. This average is then presented, at each of the reported elapsed times, as representative of the boot's permeation resistance. The reported elapsed time for each boot design is the sum of the elapsed times for the six swatches divided by six.

To estimate  $M_f$  at each elapsed time over an entire boot, the simplifying assumption is made that the exposure is uniform over the entire boot. In the analysis, each swatch was assumed to represent the area covered by the boot; the foot and lower leg. Swatches were taken from approximately the same locations for all boots; roughly midway up the side of the boot. Laboratory personnel visually estimate a location midway up each boot and cut a strip of material, with scissors, from each boot of sufficiently large surface area from which three swatches are then cut.

### 3.2.3 Relationship Between Liquid Challenge/Vapor Permeation Test Results and Skin Exposure.

The permeation test is designed to distinguish among these material swatches according to their vapor permeation resistance to chemical agents. It is not intended to specifically replicate threat scenarios that may be encountered in actual use. As previously reported by Belmonte<sup>3</sup>, it is instructive to estimate the agent dosage ( $C_{it_{skin}}$ ) that would result from such a standard agent challenge as a relative indication of possible physiological effects. This is done by converting the average  $M_f$ s to equivalent agent dosages. This relationship was developed by Fedele (written communication, Dr. P. Fedele, R&T Directorate, ERDEC, July 1997) and was reported by

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<sup>3</sup> Test Results of Level A Suits to Challenge by Chemical and Biological Warfare Agents and Simulants: Summary Report. U. S. Army Edgewood Research Development and Engineering Center, MD. August 1998, UNCLASSIFIED Report (AD A353013).

Belmonte<sup>3</sup>. For boot materials impermeable to airflow, the only mechanism for removal of agent vapor that permeates the barrier is its permeation through the skin, so the equation is:

$$\text{Agent Dosa ge (mg - min/m}^3\text{)} = \frac{M_f \text{ (ng/cm}^2\text{)}}{\text{Permeabili ty of skin to agent vapo r (cm/min)}} \quad \textbf{Equation 1}$$

where skin permeability is 2 cm/min for HD and 0.1 cm/min for GB. The agent dosage can then be compared to doses that are known to cause certain levels of toxicity. It is assumed that skin permeability to HD and GB are roughly uniform over the entire body.

#### 3.2.4 Evaluation Criteria for Liquid Challenge/Vapor Permeation Test Results.

When analyzing the test results, it is useful to determine whether the data indicate that the chemical protective boot provides percutaneous protection over some period of time. Mustard vapor can produce erythema (reddening of the skin) at localized dosages of approximately 2357 mg-min/m<sup>3</sup> on the tops of the feet. It can produce vesication (skin burns and blisters) at 4714 mg-min/m<sup>3</sup> on the tops of the feet. It was assumed that the feet were protected by the test boots and challenged uniformly by the liquid dose used on the swatches. The action of mustard is assumed to be local. Using the threshold skin reddening dosage, and the skin permeability for mustard and substituting values in Equation 1, we obtain the HD threshold value for M<sub>f</sub>.

$$\text{Threshold } M_f = 2 \times 2357 = 4714 \text{ ng/cm}^2 \quad \textbf{Equation 2}$$

Sarin vapor can produce incapacitation at percutaneous dosages of approximately 8000 mg-min/m<sup>3</sup> and can cause lethality at dosages of 15,000 mg-min/m<sup>3</sup> where exposed persons are healthy, young, fit and well-nourished males of approximately 70-kg mass. People who are smaller, less fit, etc. may exhibit adverse effects at lower dosages (C<sub>It<sub>skin</sub></sub>). Unlike mustard, Sarin



acts systemically: the body reacts to the total amount of Sarin absorbed by the body. It was assumed that the boots are incorporated into a full ensemble protecting the entire body, but that only the boots are challenged by the liquid agent. The amount of Sarin agent per unit area (average  $M_f$ ) necessary to permeate boot material covering the feet and lower legs and produce a predetermined systemic effect was estimated by using the whole-body dosage threshold of incapacitation ( $8000 \text{ mg-min/m}^3$ ), the skin permeability to Sarin vapor ( $0.1 \text{ cm/sec}$ ) from Equation 1, and 19.23% as the fractional area (proportion of the total body area represented by the hands and forearms in the BRHA model<sup>4</sup>). The relationship is:

$$\text{Threshold } M_f = (\text{Threshold dose} \times \text{skin permeability}) / (\text{fractional area}) \quad \textbf{Equation 3}$$

Substituting,

$$\text{Threshold } M_f = (8000 \times 0.1) / (0.1923) = 4159 \text{ ng/cm}^2 \quad \textbf{Equation 4}$$

The breakthrough time is the time at which the average  $M_f$  reaches the GB threshold  $M_f$ .

**Table 1. Agent Breakthrough Criteria**

Agent	Threshold Dosage (mg-min/m <sup>3</sup> )	Physiological Effect	Skin Permeability (P <sub>s</sub> ), (cm/min)	Threshold $M_f$ , (ng/cm <sup>2</sup> )
HD	2357	Erythema	2	4714
HD	4,714	Vesication	2	9428
GB	8,000	Incapacitation	0.1	4159
GB	15,000	Lethality	0.1	7798

Breakthrough time should not be interpreted as the time that a boot can be safely worn, either for HD or GB. Breakthrough times should only be used to compare boot materials.

<sup>4</sup> Fedele, Dr. Paul D., Nelson, Douglas, C., *A Method of Assessing Full Individual Protective System Performance Against Cutaneous Effects of Aerosol and Vapor Exposures*, U.S. Army Edgewood Research, Development and Engineering Center, Aberdeen Proving Ground, Maryland, October, 1995; Section 1-3 "Body Region Hazard Analysis Process" included in the report for the JSLIST Program: Cronin, Tracy D., *Final Report for the Development of the Man-In-Simulant Test (MIST) Methodology for Evaluation of Chemical/Biological (CB) Protective Garments*, TECOM Project No. 8-EI-825-ABO-004, U.S. Army Dugway Proving Ground, Dugway, Utah, April 1996.

## ACRONYMS and ABBREVIATIONS

Ct	Vapor exposure, product of vapor concentration ( $\text{mg}/\text{m}^3$ ) and time (minutes)
$C_{It_{\text{skin}}}$	Vapor exposure to skin
$\text{cm}^2$	Square centimeters
$^{\circ}\text{F}$	Temperature in degrees Fahrenheit
delta p	Differential pressure
DoD	Department of Defense
ECBC	U.S. Army Edgewood Chemical Biological Center
ERDEC	U.S. Army Edgewood Research, Development and Engineering Center
g	Gram
GB	Sarin, Isopropylmethylphosphonofluoridate
HD	Sulfur Mustard; 2,2'-Dichlorodiethylsulfide
L	Liter
$M_f$	Cumulative mass permeation through the material
$\text{m}^2$	Square meters
$\text{m}^3$	Cubic meters
mg	Milligram
$\mu\text{L}$	Microliter
ng	Nanogram
NBC	Nuclear, Biological and Chemical
PCT	Pre-concentrator tube
PPE	Personal Protective Equipment
$P_s$	Skin permeability
RH	Relative Humidity
TOP	Test Operations Procedure

**Appendix A -  
Boots Chosen for Testing**

**Table A- 1: Boots Tested**

Model	Manufacturer	Address
Dunlop Hevea Nailstep	Dunlop Hevea LTD	Liverpool, UK
Tingley Hazproof 82330	Tingley Rubber Corp.	Plainfield, NJ
LaCrosse Commander 89612	LaCrosse Footwear Inc.	LaCrosse, WI
LaCrosse Monarch 87568	LaCrosse Footwear Inc.	LaCrosse, WI
Bata Polymax 84076	Bata Shoe Inc.	Belcamp, MD
Bata Hazmax 87012	Bata Shoe Inc.	Belcamp, MD
Bata Overbooties 97591	Bata Shoe Inc.	Belcamp, MD
Servus Hazmat HZT 75107	Norcross Safety Products	Rock Island, IL
LaCrosse Chemtrex 24228	LaCrosse Footwear Inc.	LaCrosse, WI

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## **Appendix B - Modified Static Diffusion Test Procedure**

### **MODIFIED STATIC DIFFUSION TEST**

This test procedure was adapted from Test Operations Procedure (TOP) 8-2-501, Permeation and Penetration of Air-Permeable, Semipermeable and Impermeable Materials with Chemical Agents or Simulants (Swatch Testing). U.S. Army Dugway Proving Ground, UT. 3 March 1997, UNCLASSIFIED Report (AD A322329).

The following procedure will be used:

1. Upon receipt of the boots, all available information concerning the boots will be recorded; date of manufacture, lot number, serial number, materials of construction, etc.

2. From each pair of boots, one each 1 and 15/16 in diameter material swatch will be taken for HD and one like-sized material swatch will be taken for GB. If seams are present and they are flat, one each 1 and 15/16 in diameter seam swatch will be taken for HD and one like-sized seam swatch will be taken from each pair of boots for GB. If soles are flat, one each 1 and 15/16 in diameter sole swatch will be taken for HD and one each like-sized sole swatch will be taken for GB from each pair of boots. Swatches will be taken from at least 6 pairs of boots (a minimum of 6 HD swatches and 6 GB swatches will be tested) for each boot model/style.

Thickness measurements will be taken and recorded for each swatch. Each swatch will be placed in an airtight bag and given a unique serial number, which will be placed on the bag. A list of serial numbers will be kept with the swatches.

3. The environmental chamber will be controlled at a temperature of  $90 \pm 2$  °F ( $32 \pm 2$  °C) and the maximum achievable relative humidity without occurrence of condensation ( $60\% \pm 10\%$  RH). The temperature and RH readings will be checked weekly with a calibrated meter. The test cell air will be drawn from the chamber air. TOP 8-2-501 specifies that a system control and data acquisition system will be used but this system will not be used due to budget constraints. The temperature and RH will be recorded in a computer file. Flow rates will be manually recorded. TOP 8-2-501 specifies that differential pressure monitoring will be done but differential pressure gages will not be used due to budget constraints.

4. The TOP test cell will be used. When assembling, the cell lugs will be tightened by hand to finger tight. The flow rate beneath each swatch will be 1 L/min, which will be controlled by a linear mass flow controller. The flows will be checked with a calibrated test meter weekly. Each test cell will be checked for leaks after assembly by connecting it to the vacuum source and checking that the inlet flow is the same as the outlet flow on the mass flow controller (cell lugs will be retightened if flows don't match).

5. The swatches will be preconditioned overnight in the environmental chamber. Eighty-mil silicone will be used as an indicator swatch to verify that the MINICAMS can detect agent vapor permeation (one silicone swatch per 6 boot swatches). TOP 8-2-501 specifies that positive control and negative control swatches will be used but they will not be used due to budgetary and schedule limitations.

## Appendix B

6. Agents GB and HD will be used. The contamination density will be  $10 \text{ g/m}^2$  (eight  $1 \text{ }\mu\text{L}$  HD droplets or ten  $1 \text{ }\mu\text{L}$  GB droplets). The agent will be applied using the click/touch method with a Hamilton repeating dispenser. TOP 8-2-501 specifies that a robotic agent application system will be used for agent application but this will not be done due to budget constraints.

7. Seven swatches will be tested at once. MINICAMS with stream selection system will monitor vapor penetration with a 3-minute cycle per swatch. There will be 3 blank sampling intervals following the indicator swatch. Each swatch will be sampled once every 30 minutes. The MINICAMS will be standardized weekly.

8. The test length will be 24 hours.

9. The test cells and o-rings will be aerated between uses. No other cleaning method will be used.

10. The data to be reported are cumulative permeation ( $\text{ng/cm}^2$ ) versus elapsed time from contamination (minutes) for each swatch. All recorded data will be placed in laboratory notebooks and a technical report will be drafted at the conclusion of this effort.

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**Appendix C -  
Digital Photographs of Boots Tested**

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**Figure C- 1: Dunlop Hevea Nailstep Boot**



**Figure C- 2: Tingley Hazproof Boot**



**Figure C- 3: LaCrosse Commander Boot**



**Figure C- 4: LaCrosse Monarch Boot**



**Figure C- 5: Bata Polymax Boot**



**Figure C- 6: Bata Hazmax Boot**



**Figure C- 7: Bata Overbootie**



**Figure C- 8: Servus Hazmat Boot**



**Figure C- 9: LaCrosse Chemtrex Boot**

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**Appendix D -  
Permeation Results Tables**

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**Table D- 1. Average HD Permeation**

M, Average HD Cumulative Permeation (ng/cm²)																	
Avg Time (min)	Dunlop Hevea Nailstep	Avg Time (min)	Tingley Hazproof	Avg Time (min)	LaCrosse Commander Nitrile/PVC	Avg Time (min)	LaCrosse Monarch PVC	Avg Time (min)	Bata PolyMax	Avg Time (min)	Bata HazMax	Avg Time (min)	Bata Over-booties	Avg Time (min)	Servus HazMat	Avg Time (min)	LaCrosse Chemtrex Neoprene
5	3	10	4	8	1	8	2	12	2	8	5	9	3	7	13	10	6
35	46	40	25	38	14	38	24	42	9	38	43	39	21	37	180	40	36
65	84	70	44	68	58	68	56	72	16	68	75	69	542	67	500	70	57
95	117	100	63	98	131	98	97	102	23	98	104	99	1424	97	885	100	77
125	148	130	81	128	221	128	143	132	30	128	133	129	2050	127	1267	130	117
155	176	160	98	158	316	158	193	162	39	158	160	159	2489	157	1636	160	319
185	205	190	113	188	411	188	246	192	50	188	188	189	3169	187	1990	190	920
215	234	220	129	218	503	218	300	222	61	218	215	219	4017	217	2326	220	2040
245	267	250	144	248	598	248	355	252	73	248	242	249	4628	247	2643	250	3601
275	312	280	158	278	691	278	411	282	91	278	269	279	5231	277	2947	280	5451
305	378	310	172	308	776	308	469	312	122	308	296	309	5706	307	3243	310	7474
335	473	340	185	338	853	338	526	342	175	338	324	339	6120	337	3533	340	9616
365	608	370	198	368	925	368	583	372	257	368	351	369	6755	367	3828	370	11831
395	791	400	211	398	992	398	641	402	374	398	379	399	7300	397	4143	400	14078
425	1031	430	223	428	1055	428	700	432	534	428	407	429	7855	427	4495	430	16331
455	1327	460	235	458	1115	458	760	462	736	458	434	459	8493	457	4898	460	18587
485	1682	490	247	488	1172	488	823	492	980	488	462	489	9047	487	5363	490	20850
515	2098	520	259	518	1230	518	892	522	1264	518	490	519	9609	517	5897	520	23109
545	2569	550	270	548	1288	548	967	552	1580	548	520	549	10169	547	6509	550	25360
575	3096	580	282	578	1347	578	1053	582	1903	578	551	579	10761	577	7203	580	27570
605	3675	610	294	608	1406	608	1149	612	2258	608	583	609	11424	607	7983	610	29785
635	4299	640	305	638	1466	638	1258	642	2667	638	620	639	12274	637	8844	640	32048
665	4959	670	316	668	1529	668	1381	672	3103	668	660	669	13236	667	9778	670	34310
695	5656	700	328	698	1596	698	1524	702	3561	698	705	699	14110	697	10784	700	36532
725	6335	730	339	728	1669	728	1688	732	4010	728	756	729	14791	727	11856	730	38751
755	6971	760	351	758	1745	758	1877	762	4441	758	814	759	15517	757	12993	760	40972
785	7624	790	363	788	1828	788	2094	792	4803	788	880	789	16426	787	14194	790	43193
815	8436	820	376	818	1920	818	2340	822	5173	818	954	819	17216	817	15457	820	45345
845	9390	850	388	848	2020	848	2618	852	5624	848	1038	849	17975	847	16774	850	47495
875	10271	880	401	878	2130	878	2935	882	6088	878	1132	879	18895	877	18133	880	49740
905	11053	910	414	908	2252	908	3299	912	6529	908	1236	909	19835	907	19527	910	51950
935	11912	940	429	938	2386	938	3717	942	6928	938	1355	939	20651	937	20956	940	54101
965	12915	970	444	968	2544	968	4194	972	7366	968	1488	969	21469	967	22418	970	56291
995	13939	1000	460	998	2730	998	4725	1002	7904	998	1630	999	22334	997	23909	1000	58514
1025	14879	1030	478	1028	2947	1028	5311	1032	8490	1028	1784	1029	23257	1027	25429	1030	60732
1055	15798	1060	496	1058	3196	1058	5957	1062	9055	1058	1952	1059	24259	1057	26973	1060	62972
1085	16851	1090	517	1088	3477	1088	6662	1092	9644	1088	2135	1089	25257	1087	28535		
1114	17852	1120	541	1118	3793	1118	7427	1122	10284	1118	2331	1119	26254	1117	30111		
1141	18792	1150	566	1148	4134	1148	8246	1152	10935	1148	2543	1149	27250	1147	31704		
1168	19823	1180	595	1178	4504	1178	9123	1182	11594	1178	2774	1179	28243	1177	33310		
1193	20822	1210	627	1208	4904	1208	10062	1212	12131	1208	3020	1209	29222	1207	34924		
1219	21833	1240	663	1238	5330	1238	11067	1242	12538	1238	3281	1239	30201	1237	36551		
1243	22804	1270	702	1268	5786	1268	12121	1272	13060	1268	3554	1269	31189	1267	38187		
1267	23783	1300	746	1298	6266	1298	13205	1302	13663	1298	3841	1299	32170	1297	39829		
1291	24772	1330	793	1328	6771	1328	14323	1330	14217	1328	4142	1329	33144	1326	41325		
1315	25767	1360	846	1358	7294	1358	15404	1359	14808	1358	4456	1359	34111	1354	42827		
1339	26776	1390	905	1388	7836	1388	16508	1387	15436	1388	4784	1389	35075	1383	44333		

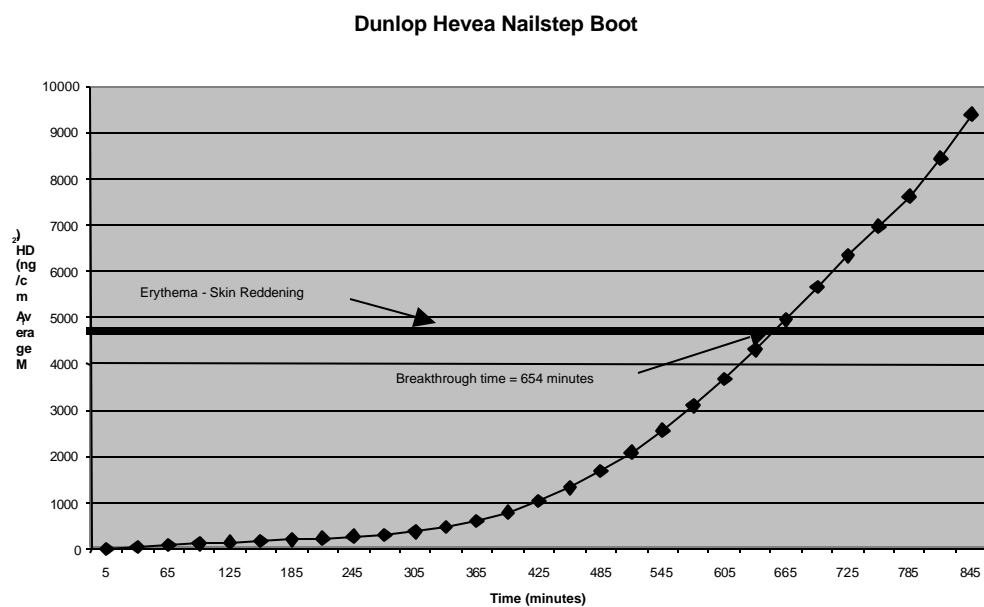
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**Table D- 2. Average GB Permeation**

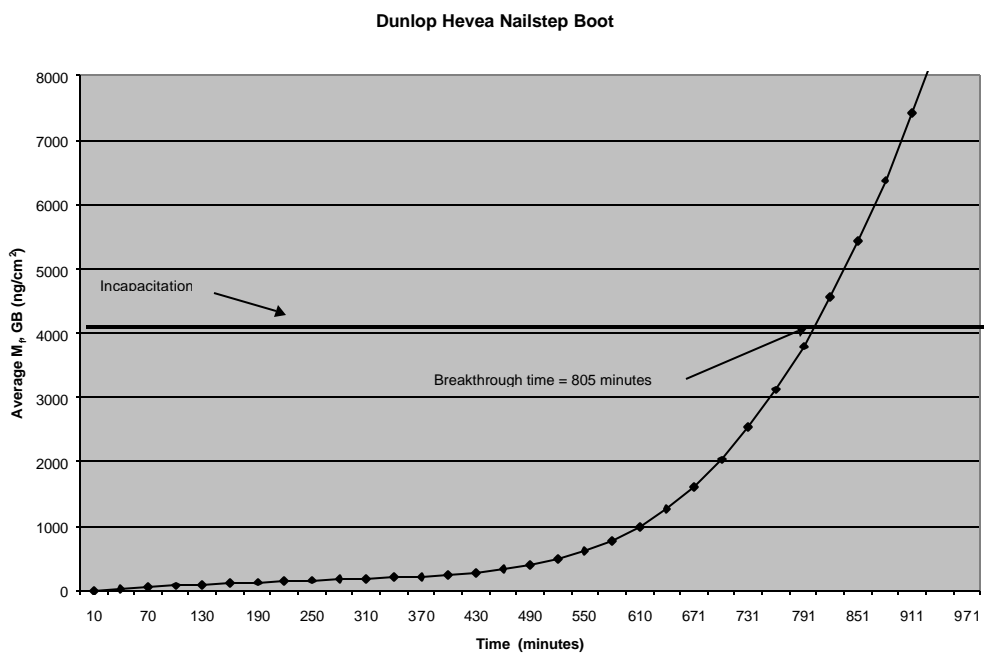
M, Average GB Cumulative Permeation (ng/cm <sup>2</sup> )																	
Avg Time (min)	Dunlop Hevea Nailstep	Avg Time (min)	Tingley Hazproof	Avg Time (min)	LaCrosse Commander Nitrile/PVC	Avg Time (min)	LaCrosse Monarch PVC	Avg Time (min)	Bata PolyMax	Avg Time (min)	Bata HazMax	Avg Time (min)	Bata Over-booties	Avg Time (min)	Servus HazMat	Avg Time (min)	LaCrosse Chemtrex Neoprene
10	1	9	3	11	3	8	1	9	1	10	1	7	0	11	2	8	1
40	19	39	26	41	37	38	15	39	12	40	10	37	5	41	22	38	20
70	46	69	49	71	89	68	38	70	23	70	25	67	320	71	42	68	37
100	71	99	65	101	139	98	65	100	29	100	41	97	3754	101	51	98	43
130	92	130	80	131	183	128	93	130	35	130	55	127	10305	131	58	128	48
160	110	160	94	161	223	158	117	160	40	161	69	157	17157	161	65	158	52
190	127	190	110	192	261	188	140	190	45	191	81	187	24022	192	72	188	56
220	142	220	126	222	296	218	161	220	49	221	92	217	30908	222	78	218	59
250	157	250	142	252	330	248	180	251	54	251	102	247	37799	252	84	248	62
280	170	280	157	282	362	278	198	281	58	281	112	277	44692	282	90	278	65
310	184	311	171	312	392	308	214	311	63	311	121	307	51589	312	96	308	68
340	200	341	185	342	420	338	230	341	66	342	130	337	58492	342	101	338	70
370	218	371	198	373	447	368	246	371	70	372	138	367	65406	373	107	368	73
400	243	401	211	403	472	398	261	401	73	402	146	397	72333	403	112	398	75
430	277	431	224	433	496	428	276	432	77	432	153	427	79251	433	117	428	78
460	324	461	236	463	519	458	291	462	81	462	160	457	86143	463	122	458	80
490	390	492	248	493	541	488	306	492	86	492	166	487	93014	493	126	488	82
520	482	522	259	523	562	518	320	522	91	523	174	517	99865	523	131	518	85
550	606	552	270	554	582	548	333	552	96	553	181			554	136	548	87
580	770	582	281	584	601	578	346	582	103	583	189			584	140	578	89
610	983	612	292	614	619	608	359	613	110	613	197			614	145	608	91
641	1257	642	302	644	636	638	372	643	118	643	204			644	150	638	93
671	1604	673	313	674	653	668	386	673	127	673	211			674	154	668	96
701	2027	703	323	704	669	698	401	703	138	704	217			704	158	698	98
731	2530	733	333	735	684	728	418	733	151	734	223			735	163	728	101
761	3116	763	343	765	699	758	436	763	167	764	230			765	167	758	103
791	3795	793	353	795	714	788	455	794	183	794	236			795	172	789	105
821	4566	823	362	825	728	818	477	824	203	824	242			825	176	819	107
851	5423	854	372	855	742	848	502	854	225	854	248			855	181	849	109
881	6377	884	382	885	755	878	530	884	250	885	254			885	185	879	112
911	7423	914	391	916	768	908	562	914	278	915	260			916	189	909	114
941	8561	944	401	946	781	938	598	944	310	945	266			946	193	939	116
971	9802	974	411	976	794	968	640	975	345	975	272			976	197	969	118
1001	11143	1004	420	1006	806	998	687	1005	383	1005	278			1006	201	999	120
1032	12576	1035	430	1036	819	1028	740	1035	425	1035	283			1036	206	1029	122
1062	14109	1065	439	1066	831	1058	800	1065	472	1066	289			1066	210	1059	124
1092	15740	1095	448	1097	843	1088	866	1095	522	1096	294			1097	214	1089	126
1122	17467	1125	457	1127	855	1118	939	1125	577	1126	300			1127	218	1119	128
1152	19283	1155	466	1157	867	1148	1020	1156	636	1156	305			1157	222	1149	130
1182	21183	1185	475	1187	879	1178	1109	1186	699	1186	311			1187	226	1179	132
1213	23158	1216	484	1217	892	1208	1207	1216	768	1216	316			1217	230	1209	134
1243	25215	1246	493	1247	904	1238	1314	1246	840	1247	321			1247	234	1239	136
1273	27367	1276	502	1278	916	1268	1432	1276	917	1277	327			1278	238	1269	138
1303	29597	1306	511	1308	929	1298	1559	1306	998	1307	332			1308	242	1299	140
1333	31894	1336	520	1338	942	1328	1697	1337	1084	1337	337			1338	246	1329	142
1364	34251	1367	528	1368	955	1358	1846	1367	1175	1367	342			1368	250	1359	144

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## **Appendix E - Permeation Results Plots**



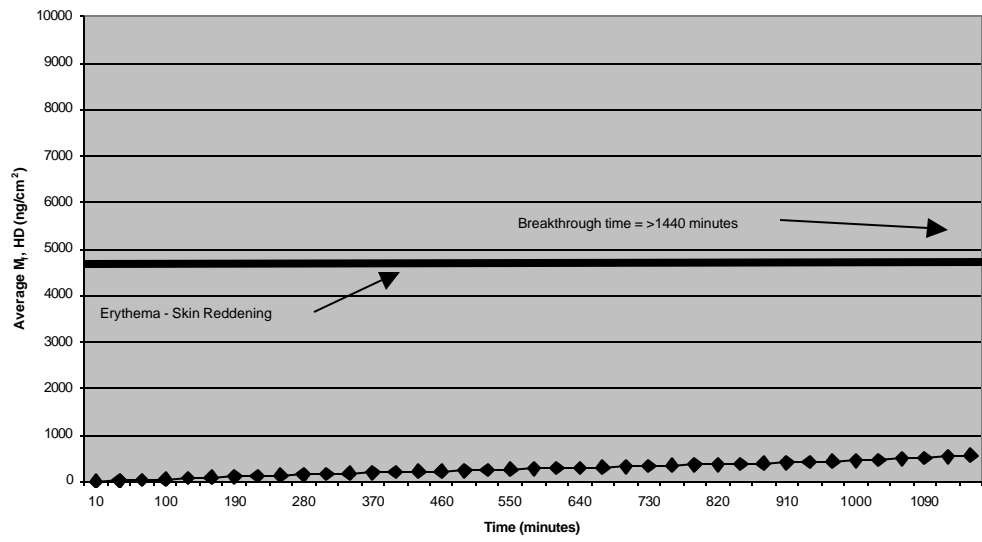
**Figure E- 1: Dunlop Hevea Nailstep - Average HD Cumulative Permeation**



**Figure E- 2: Dunlop Hevea Nailstep - Average GB Cumulative Permeation**

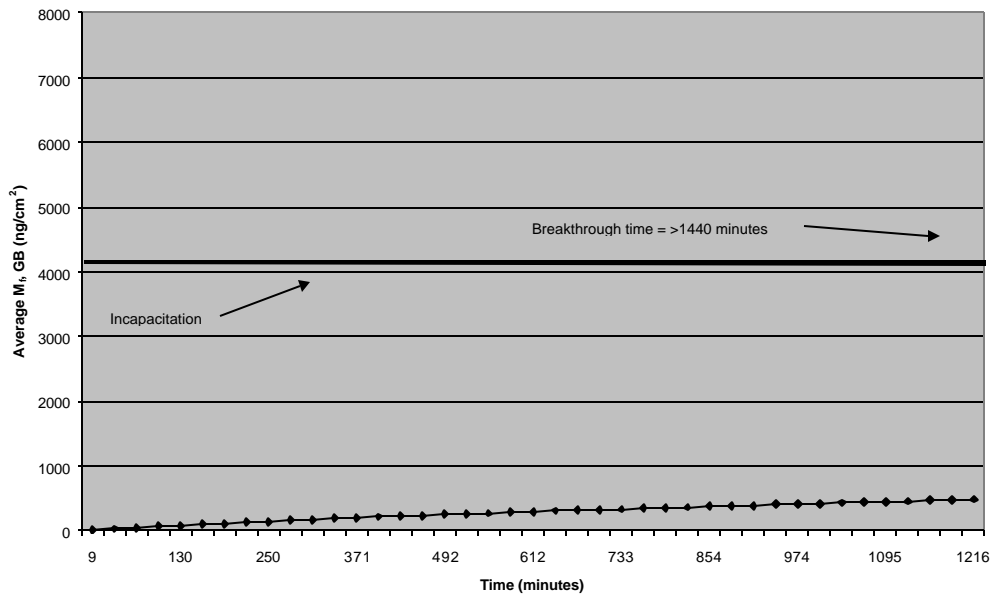


### Tingley Hazproof Boot



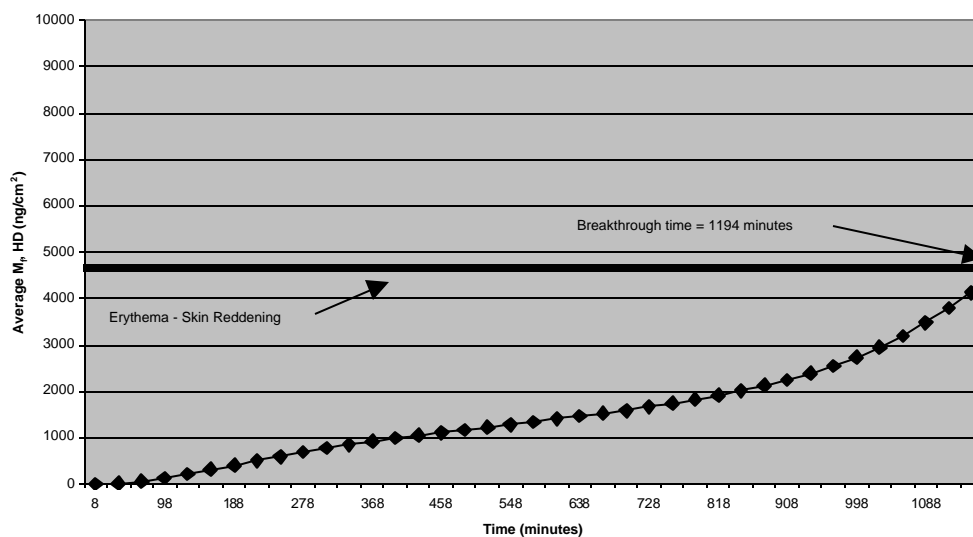
**Figure E- 3: Tingley Hazproof: Average HD Cumulative Permeation**

### Tingley Hazproof Boot



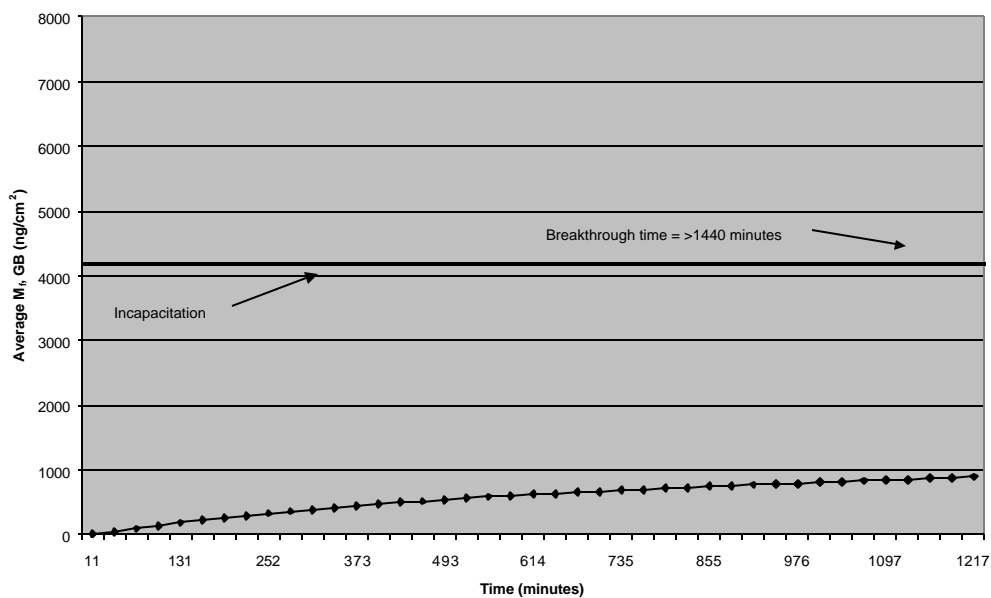
**Figure E- 4: Tingley Hazproof: Average GB Cumulative Permeation**

### LaCrosse Commander Nitrile/PVC Boot

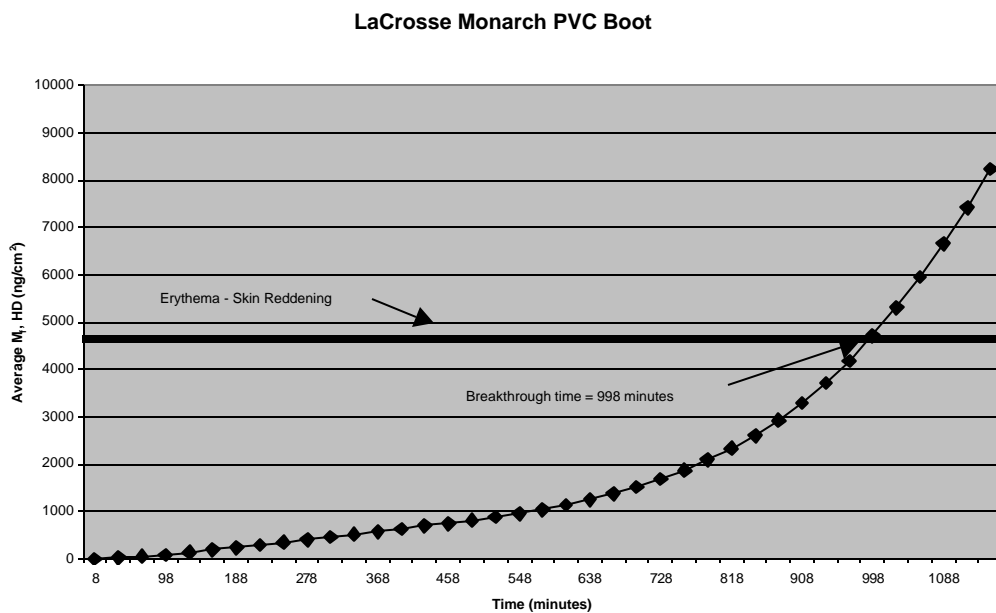


**Figure E- 5: LaCrosse Commander: Average HD Cumulative Permeation**

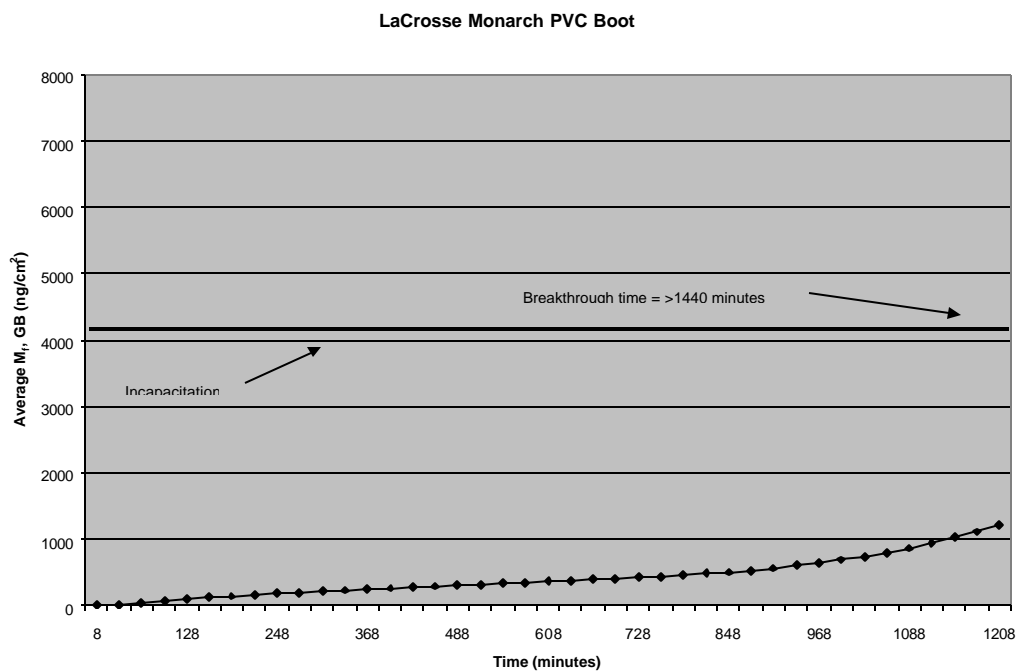
### LaCrosse Commander Nitrile/PVC Boot



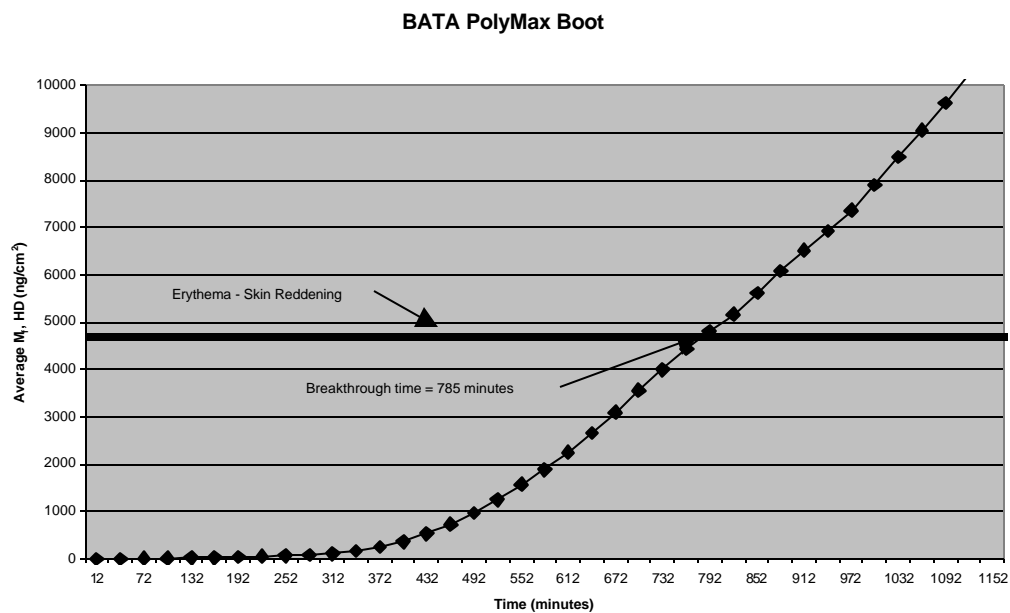
**Figure E- 6: LaCrosse Commander: Average GB Cumulative Permeation**



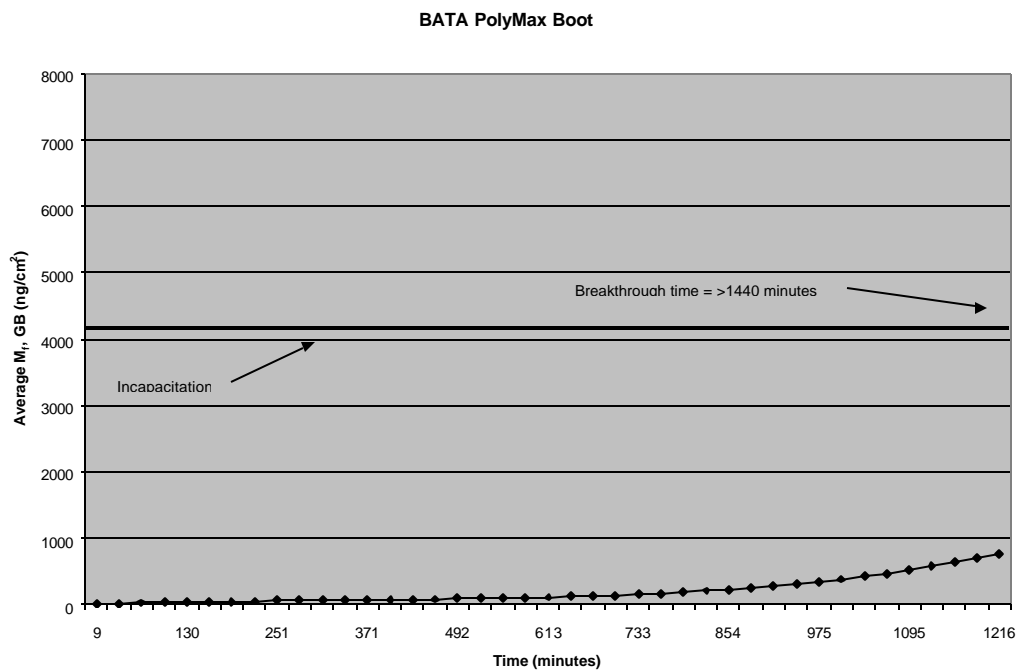
**Figure E- 7: LaCrosse Monarch: Average HD Cumulative Permeation**



**Figure E- 8: LaCrosse Monarch: Average GB Cumulative Permeation**



**Figure E- 9: Bata Polymax: Average HD Cumulative Permeation**



**Figure E- 10: Bata Polymax: Average GB Cumulative Permeation**

### BATA HazMax Boot

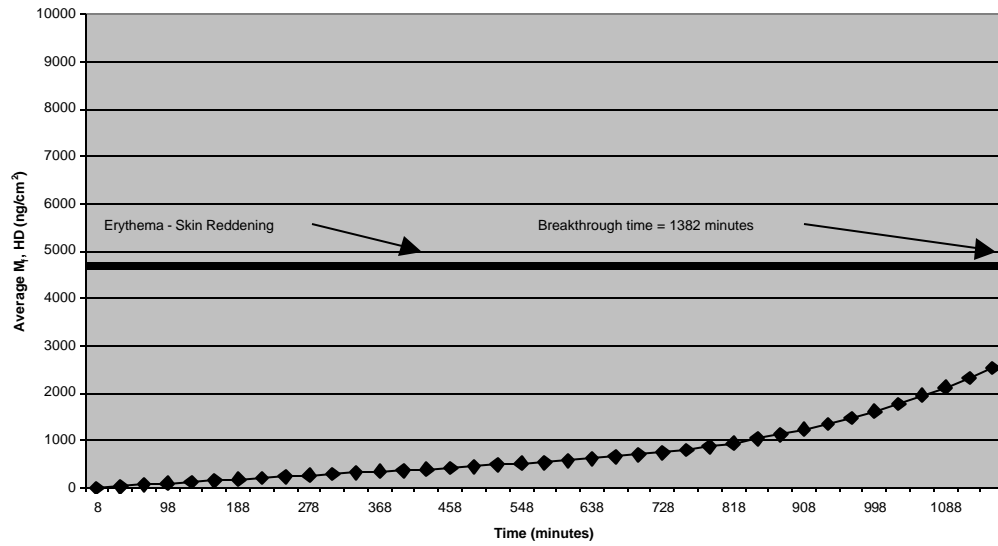


Figure E- 11: Bata Hazmax: Average HD Cumulative Permeation

### BATA HazMax Boot

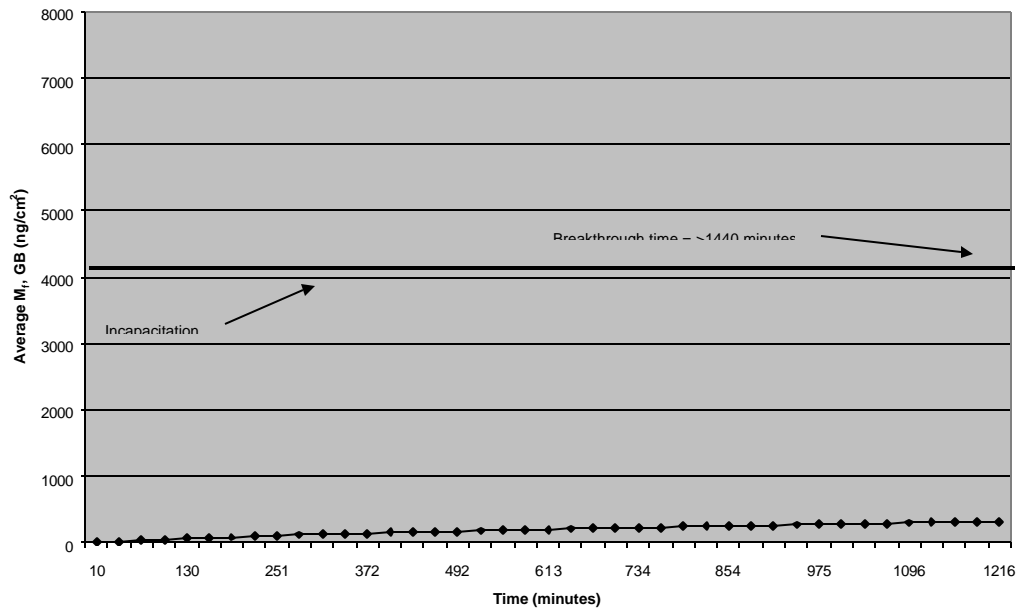
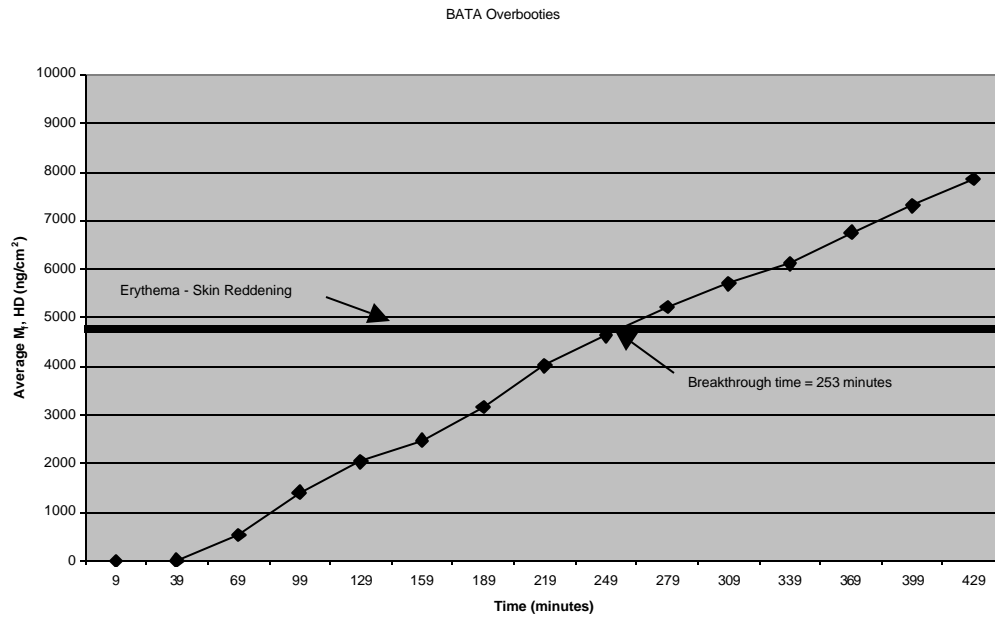
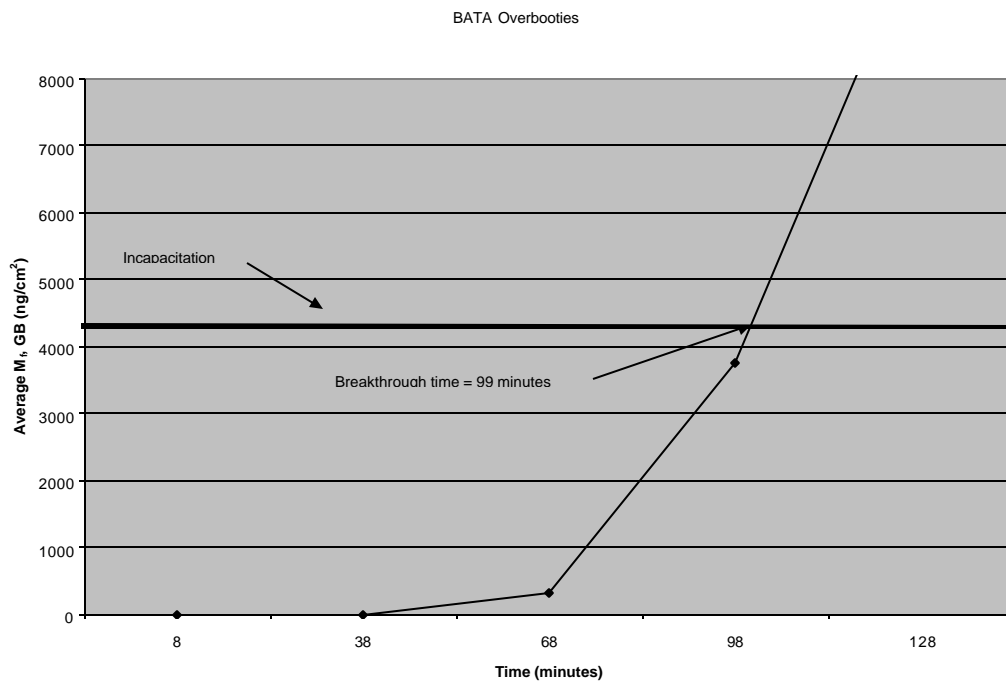


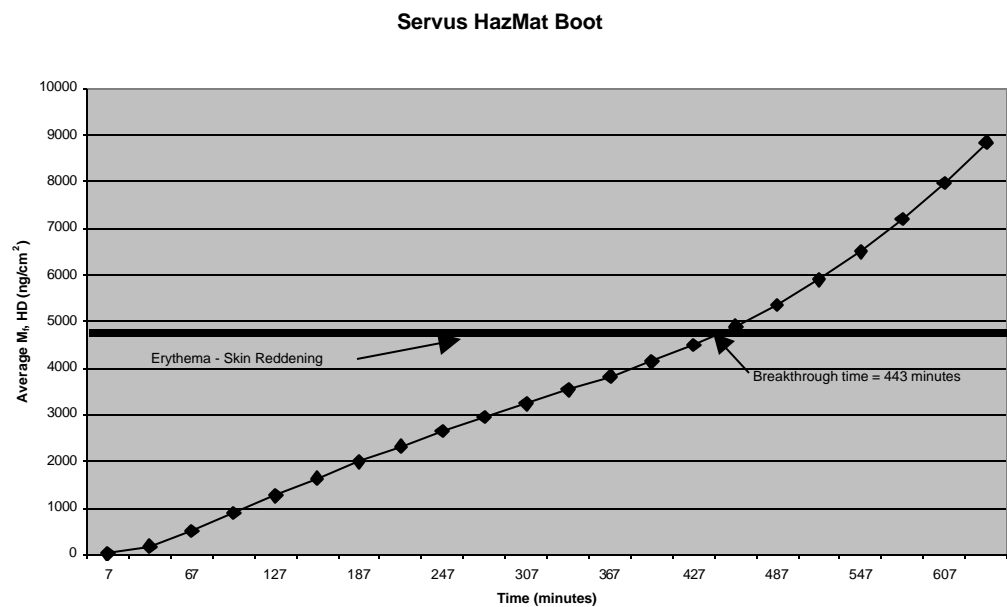
Figure E- 12: Bata Hazmax: Average GB Cumulative Permeation



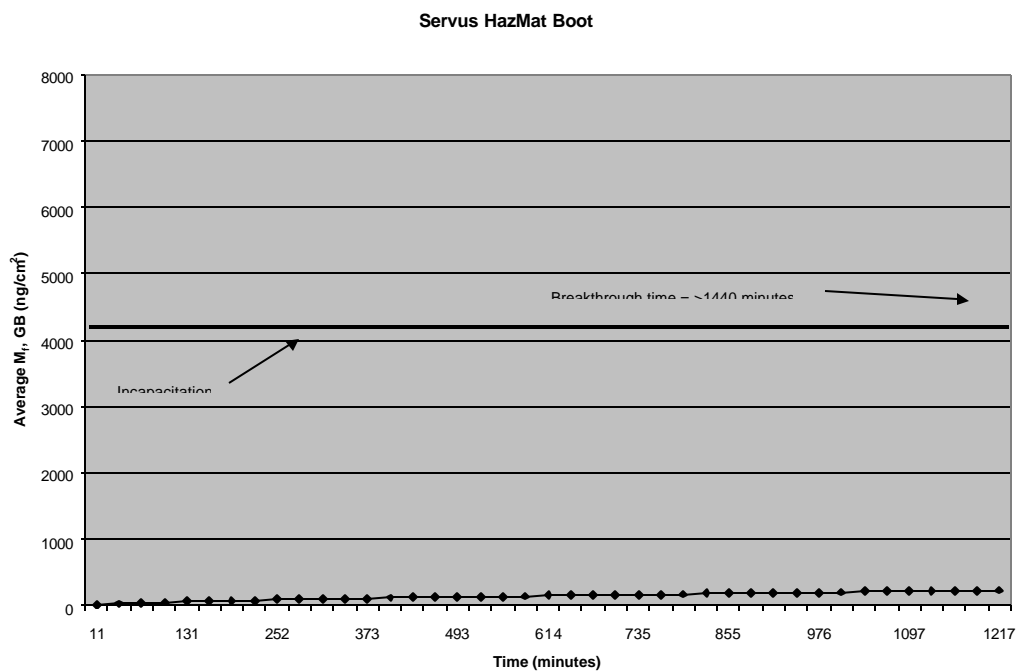
**Figure E- 13: Bata Overbooties: Average HD Cumulative Permeation**



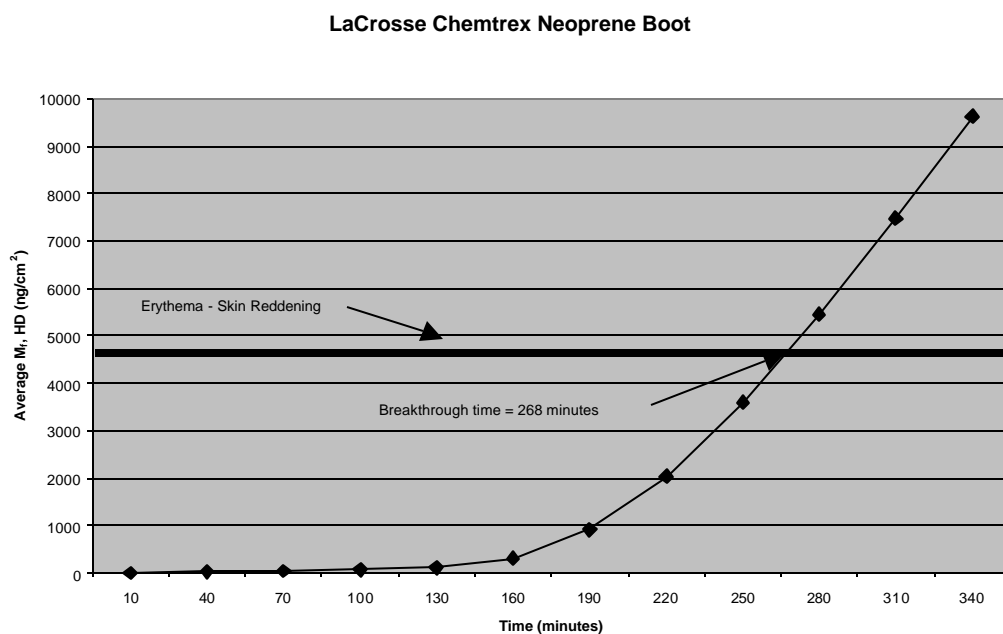
**Figure E- 14: Bata Overbooties: Average GB Cumulative Permeation**



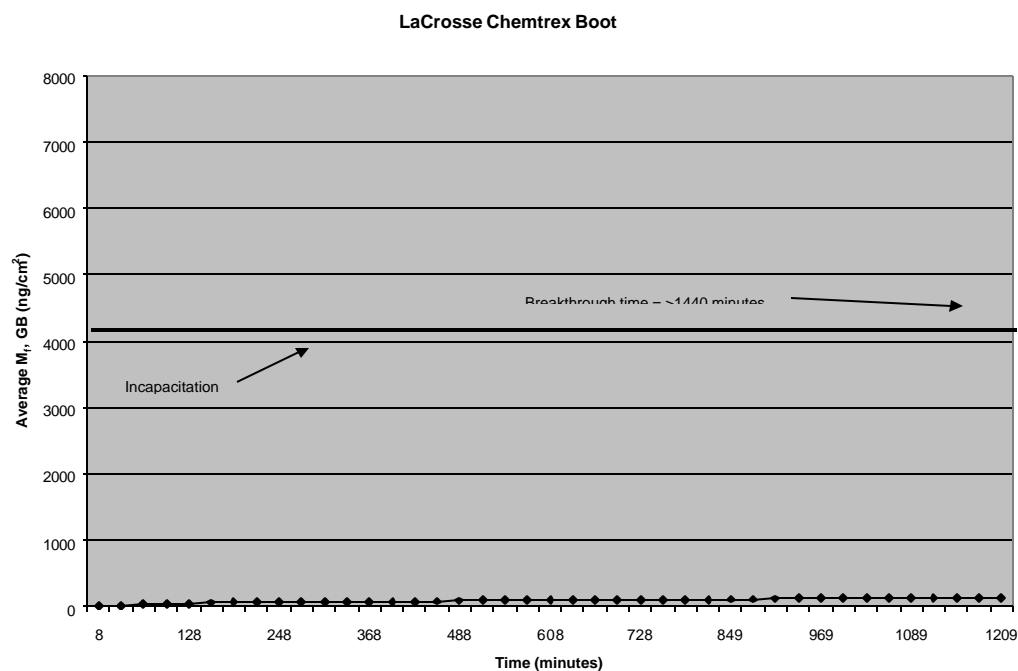
**Figure E- 15: Servus Hazmat: Average HD Cumulative Permeation**



**Figure E- 16: Servus Hazmat: Average GB Cumulative Permeation**



**Figure E- 17: LaCrosse Chemtrex: Average HD Cumulative Permeation**



**Figure E- 18: LaCrosse Chemtrex: Average GB Cumulative Permeation**



**Appendix F -  
Overall Test Results**

**Table F- 1. Overall Test Results**

Boot Model	Breakthrough Time (min)	
	HD	GB
Dunlop Hevea Nailstep	654	805
Tingley Hazproof 82330	>1440	>1440
LaCrosse Commander 89612	1194	>1440
LaCrosse Monarch 87568	998	>1440
Bata Polymax 84076	785	>1440
Bata Hazmax 87012	1382	>1440
Bata Overbooties 97591	253	99
Servus Hazmat HZT 75107	443	>1440
LaCrosse Chemtrex 24228	268	>1440